1

1   **Improved Vertical External Cavity Surface Emitting Laser**

2

3   The present invention relates to an improved Vertical

4   External Cavity Surface Emitting Laser (VECSEL) and in

5   particular to a VECSEL that exhibits improved wavelength

6   tuning characteristics.

7

8   Diode-pumped and electrically pumped VECSELs are an

9   attractive format of semiconductor laser known to those

10   skilled in the art for scientific, instrumentation and

11   non-linear optics applications. The design and

12   fabrication of a VECSEL laser with Circular TEM_{00} output

13   beams has been described by Kusnetsov et al (IEEE Journal

14   of selected Topics in Quantum Electronics Vol. 5, Page

15   561 – 573 (1999) *"Design and Characteristics of High-*

16   *Power (>0.5W CW) Diode-Pumped Vertical-External-Cavity*

17   *Surface- Emitting Semiconductor Lasers with Circular TEM_{00}*

18   *Beams"*).

19

20   The optical gain medium within a VECSEL is provided by

21   the recombination of electrical carriers within very thin

22   layers of a semiconductor material. These layers are

23   generally termed quantum-well (QW) layers or active

1 layers exhibiting a typical thickness of around 150 Å or

2 less.

3

4 Application of intracavity spectral and temporal control

5 techniques such as picosecond and subpicosecond mode-

6 locking, single-frequency operation and intracavity

7 second-harmonic generation have also been demonstrated

8 see:

9 • Garnache et al. Appl. Phys. Lett. Vol 80 Page 3892-3894

10   (2002) *Sub 500-fs Soliton-Like Pulse in a Passively*

11   *Mode-Locked Broadband Surface-Emitting Laser with 100mW*

12   *Average Power"*;

13 • Holm et al. IEEE Photon. Technol. Lett. Vol 11 Page

14   1551-1553 (1999) *Actively stabilised Single-Frequency*

15   *Vertical-Cavity AlGaAs Laser"*; and

16 • Schiehlen et al. IEEE Photon. Technol. Lett. Vol 14

17   Page 777-779 (2002) *Diode-Pumped Semiconductor Disk*

18   *Laser With Intracavity Frequency Doubling using Lithium*

19   *Triborate (LBO)"*, respectively.

20

21 A significant limiting factor in all of the

22 aforementioned systems is that their output power is

23 greatly limited by the thermal response of the gain

24 medium.   Typically, without employing thermoelectric

25 cooler (TEC) mounting techniques or cooling strategically

26 deployed heat sinks with chilled water, both of which are

27 well known to those skilled in the art, the output powers

28 at room temperatures are limited to a few 10's of mW.

29 The employment of these cooling methods act to improve

30 the output powers but are generally very inefficient due

31 to the fact that the heat must be removed from the gain

32 medium via the substrate of the structure.

33

The prior art teaches of several methods for improving the efficiency of VECSEL cooling systems. The first involves growing the gain structure in reverse order, mounting on a heatsink and etching away the substrate. However, the resultant scattering due to poor surface quality remains a significant problematic feature within low gain lasers that usually tolerate only very little losses (~4%).

Alford et al. described an alternative method for removing heat from the gain region that involves no post-growth alterations to the structure (see J. Opt. Soc. Am. B Vol. 19, Page 663 (2002) *"High Power and Good Beam Quality at 980nm from a Vertical External-Cavity Surface-Emitting Laser"*). In particular this document teaches of an InGaAs-based VECSEL that employs, in conjunction with a thermoelectric cooler, a sapphire heatspreader capillary bonded in optical contact with the epi-side (or active surface) of the gain structure. More recently, Hastie et al. have described a VECSEL that employs an intracavity Silicon Carbide (SiC) heatspreader that is optically contacted to the active surface of the gain medium (see IEEE Photon. Technol. Lett. Vol 15 Page 894-896 (2003) *"0.5 W Single Transverse-Mode Operation of an 850nm Diode Pumped Surface-Emitting Semiconductor Laser"*). Generally, Silicon Carbide has been shown to exhibit superior heat spreading characteristics than heatspreaders comprising Sapphire.

In order to produce single frequency operation it is known to those skilled in the art to incorporate intracavity polarisation selecting elements such as birefringent filters, orientated at Brewster's angle, and

1   an etalon within the laser cavity. Wavelength scanning

2   can then be achieved via a number of known techniques

3   e.g. the incorporation of stabilisation to a side of a

4   transmission peak of an external reference cavity. Such

5   techniques are currently employed to produce tuneable

6   Ti:Sapphire and Dye lasers that find particular

7   application in the field of high resolution spectroscopy.

8

9   It is known that the gain medium of a VECSEL possesses a

10   relatively high gain bandwidth that provides the

11   potential for a VECSEL to be tuned approximately 20 nm

12   either side of the engineered wavelength. However, in

13   practice it has been found that the above laser frequency

14   stabilisation and wavelength scanning techniques do not

15   lend themselves to be readily incorporated within the

16   described VECSELs. This is principally due to the fact

17   that there is significant modulation of the output power

18   of the VECSEL as the laser's operating wavelength is

19   scanned (between 10 – 30%) due to the heatspreader acting

20   as an additional intracavity etalon. Furthermore, both

21   Sapphire and Silicon Carbide heat spreading elements are

22   found to interfere with the polarisation selection

23   properties of any intracavity birefringent filter thus

24   reducing the frequency stability and tuneability of the

25   cavity.

26

27   It is an object of aspects of the present invention to

28   provide a Vertical External Cavity Surface Emitting Laser

29   (VECSEL) that overcomes one or more of the limiting

30   features on frequency stability and frequency tuning

31   associated with the VECSELs described in the prior art.

32

1 According to a first aspect of the present invention
2 there is provided a Vertical External Cavity Surface
3 Emitting Laser comprising: a semiconductor wafer
4 structure, containing a gain medium and a Bragg
5 reflecting region; and a heatspreader associated with the
6 wafer structure such that the gain medium is located
7 between the heatspreader and the Bragg reflecting region,
8 wherein the heatspreader comprises a non-birefringent
9 material.
10
11 Preferably the heatspreader comprises a first surface
12 upon which is located an anti-reflection coating.
13
14 According to a second aspect of the present invention
15 there is provided a Vertical External Cavity Surface
16 Emitting Laser comprising: a semiconductor wafer
17 structure containing a gain medium and a Bragg reflecting
18 region; and a heatspreader associated with the wafer
19 structure such that the gain medium between is located
20 between the heatspreader and the Bragg reflecting region,
21 wherein the heatspreader comprises a first surface upon
22 which is located an anti-reflection coating.
23
24 Most preferably the heatspreader comprises a non-
25 birefringent material.
26
27 According to a third aspect of the present invention
28 there is provided a Vertical External Cavity Surface
29 Emitting Laser comprising: a semiconductor wafer
30 structure containing a gain medium and a Bragg reflecting
31 region; and a heatspreader associated with the wafer
32 structure such that the gain medium is located between
33 the heatspreader and the Bragg reflecting region, wherein

the heatspreader comprises a non-birefringent material and a first surface upon which is located an anti-reflection coating.

Preferably the anti-reflection coating is optimised for efficient operation with a refractive index of the non-birefringent material and a lasing frequency of the laser.

Preferably the first surface of the heatspreader comprise a wedge.

Most preferably the heatspreader comprises a single diamond crystal.

Optionally lasing of the Vertical External Cavity Surface Emitting Laser is achieved by optical excitement of the gain medium. Alternatively, lasing of the Vertical External Cavity Surface Emitting Laser is achieved by electrical excitement of the gain medium.

Preferably the laser further comprises an intracavity polarisation selecting element that provides a first means for selecting the operating frequency of the laser.

Preferably the intracavity polarisation selecting element comprises a birefringent filter orientated at Brewster's angle.

Preferably the laser further comprises an intracavity etalon that provides a second means for selecting the operating frequency of the laser.

1 Preferably the laser further comprises an external
2 reference cavity that allows for the frequency
3 stabilisation of the laser output to a side of a
4 transmission peak of the external cavity.
5
6 Optionally the laser comprises a three mirror folded
7 cavity arrangement.
8
9 Preferably the laser further comprises a cavity mirror
10 mounted on a first piezoelectric crystal and an output
11 coupler mounted on a second piezoelectric crystal wherein
12 the combined movement of the cavity mirror and the output
13 coupler provides a first means for frequency tuning the
14 output of the laser.
15
16 Alternatively, the laser further comprises a pair of
17 Brewster plates and a cavity mirror mounted on a
18 piezoelectric crystal wherein the combined movement of
19 the Brewster plates and the cavity mirror provide a
20 second means for frequency tuning the output of the
21 laser.
22
23 According to a fourth aspect of the present invention
24 there is provided a frequency scanning Vertical External
25 Cavity Surface Emitting Laser suitable for use in high
26 resolution spectroscopy experiments comprising: apparatus
27 for selecting and stabilising the operating frequency of
28 the laser; apparatus for scanning the operating frequency
29 of the laser; a semiconductor wafer structure containing
30 a gain medium and a Bragg reflecting region; and a
31 heatspreader associated with the wafer structure such
32 that the gain medium is located between the heatspreader

1   and the Bragg reflecting region, wherein the heatspreader

2   comprises a non-birefringent material.

3

4   Preferably the heatspreader comprises a first surface

5   upon which is located an anti-reflection coating.

6

7   Preferably the apparatus for selecting and stabilising

8   the operating frequency of the laser comprises an

9   intracavity polarisation selecting element that provides

10 a first means for selecting the operating frequency of

11 the laser.

12

13 Optionally the apparatus for selecting and stabilising

14 the operating frequency of the laser further comprises an

15 intracavity etalon that provides a second means for

16 selecting the operating frequency of the laser.

17

18 Optionally the apparatus for selecting and stabilising

19 the operating frequency of the laser further comprises an

20 external reference cavity that allows for the frequency

21 stabilisation of the laser output to a side of a

22 transmission peak of the external cavity.

23

24 Preferably the apparatus for scanning the operating

25 frequency of the laser comprises a cavity mirror mounted

26 on a first piezoelectric crystal and an output coupler

27 mounted on a second piezoelectric crystal wherein the

28 combined movement of the cavity mirror and the output

29 coupler provides a first means for frequency tuning the

30 output of the laser.

31

32 Alternatively, the apparatus for scanning the operating

33 frequency of the laser comprises a pair of Brewster

1 plates and a cavity mirror mounted on a piezoelectric

2 crystal wherein the combined movement of the Brewster

3 plates and the cavity mirror provides a second means for

4 frequency tuning the output of the laser.

5

6 Preferably the anti-reflection coating is optimised for

7 efficient operation with a refractive index of the non-

8 birefringent material and a lasing frequency of the

9 laser.

10

11 Preferably the first surface of the heatspreader comprise

12 a wedge.

13

14 Most preferably the heatspreader comprises a single

15 diamond crystal.

16

17 Aspects and advantages of the present invention will

18 become apparent upon reading the following detailed

19 description and upon reference to the following drawings

20 in which:

21

22 Figure 1 presents a schematic representation of an

23   improved Vertical External Cavity Surface

24   Emitting Laser (VECSEL) that incorporates

25   intracavity elements for single frequency

26   selection;

27

28 Figure 2 presents:

29   (a) a schematic representation; and

30   (b) a schematic bandgap diagram,

31   of the gain medium of a 980 nm VECSEL of

32   Figure 1;

33

1   Figure 3   presents further detail of the cooling
2   apparatus and a heatspreader employed by the
3   VECSEL of Figure 1;
4
5   Figure 4   presents an output power curve, as a function
6   of pump power, for the VECSEL of Figure 1
7   designed to operate around a 980 nm central
8   output wavelength;
9
10 Figure 5   presents a measured residual frequency noise
11   output for the 980 nm VECSEL of Figure 1;
12
13 Figure 6   presents a measured wavelength tuning curve for
14   the 980 nm VECSEL of Figure 1 when coupled to a
15   transmission peak of an external reference
16   cavity; and
17
18 FIGURE 7   presents schematic detail of:
19   (a)   an on axis back pumped VECSEL;
20   (b)   an on axis back pumped VECSEL that
21   incorporates a second heatspreader; and
22   (c)   an off-axis back pumped VECSEL;
23   in accordance with various aspects of the
24   present invention.
25
26 Referring to Figure 1 a schematic representation of a
27 Vertical External Cavity Surface Emitting Laser (VECSEL)
28 1, in accordance with an aspect of the present invention
29 is provided.   The VECSEL 1 can be seen to comprise a
30 semiconductor wafer structure 2 mounted within a cooling
31 apparatus 3 that is located within a three mirror folded
32 cavity arrangement.
33

1   A first mirror within the cavity arrangement comprises a

2   Bragg reflector region 4 integrated within the wafer

3   structure 2 (further details of which are outlined

4   below). A second mirror comprises a standard curved

5   cavity mirror 5 mounted on a first piezoelectric crystal

6   6 so allowing for fine adjustment of the length of the

7   cavity. An output coupler 7, mounted on a second

8   piezoelectric crystal 8 so allowing for coarse adjustment

9   of the length of the cavity, is then employed as the

10 third cavity mirror. Between the curved cavity mirror 5

11 and the output coupler 7 are located a birefringent

12 filter 9 employed to provide coarse frequency selection

13 within the cavity and a solid etalon 10 employed for fine

14 frequency selection of the operating wavelength. The

15 wafer structure 2 is optically pumped by initially

16 coupling the output of a pump laser source (not shown)

17 into an optical fibre 11. Thereafter, the coupled pump

18 laser output is focussed via two input lens elements 12

19 onto the wafer structure 2.

20

21 A schematic representation of the wafer structure 2 is

22 presented in Figure 2(a). The wafer structure 2 is grown

23 by a metal-organic chemical vapour deposition (MOCVD)

24 technique on a 2 inch (5.08 cm) 500 mm thick (001) GaAs

25 substrate 13. The wafer structure 2 comprises a single

26 distributed Bragg reflector region 4, a gain medium 14, a

27 carrier confinement potential barrier 15 and an oxidation

28 prevention layer 16.

29

30 The Bragg reflector region 4 comprises thirty pairs of

31 AlAs-GaAs quarter-wave layers that exhibit a total

32 reflectivity greater than 99.9% centred at 980 nm while

33 the carrier confinement potential barrier comprises a

1   single wavelength-thick $Al_{0.3}Ga_{0.7}As$ layer. The oxidation
2   prevention layer comprises a thin $In_{0.48}Ga_{0.52}P$ cap.
3
4   The gain medium 14 comprises twelve 6 nm thick $In_{0.16}GaAs$
5   quantum   wells   equally   spaced   between   half-wave
6   $Al_{0.06}Ga_{0.8}As$/GaAsP structures that allow the VECSEL 1 to be
7   optically pumped at 808 nm while generating an output in
8   the range of 970 – 995 nm. (referred to below as the 980
9   nm VECSEL)
10
11 A schematic representation of the lasing mechanism is
12 presented in the bandgap diagram of Figure 2(b). The
13 pump field 17 is absorbed in the barrier regions and
14 carriers thereafter diffuse into the quantum wells so as
15 to produce the required population inversion for lasing
16 to take place.
17
18 Figure 3 presents further detail of the cooling apparatus
19 3 and heatspreader 18 employed in order to improve the
20 operating characteristics of the VECSEL 1. In particular
21 the   cooling   apparatus   3   comprises   a   standard
22 thermoelectric cooler 19 while the heat spreader 18
23 comprises a single diamond crystal that comprises an
24 external, wedged face 20. A high performance anti-
25 reflection coating is deposited on the surface of the
26 wedged face 20.
27
28 The single diamond crystal heatspreader 18 is bonded in
29 optical contact with the wafer structure 2 so that the
30 gain medium 14 is located between the heatspreader 18 and
31 the Bragg reflector region 4. The wafer structure 2 and
32 heatspreader 18 are then clamped on top of a layer of
33 indium foil 21 onto the thermoelectric cooler 19.

1

2 Single diamond crystal is suited to be employed as the

3 heatspreader 18 since it exhibits comparable thermal

4 conductivity levels as Sapphire and Silicon Carbide.

5 Thus, the described arrangement allows the heatspreader

6 18 to immediately spread the heat generated within the

7 gain medium 14 by the pump field 17 to the cooling

8 apparatus 3 after it has propagated only a limited

9 distance into the gain medium 14, so significantly

10 increasing the efficiency of the device. In addition

11 there are further inherent advantages of employing the

12 single diamond crystal as the heatspreader 18 over those

13 described in the prior art. These reside in the fact

14 that the single diamond crystal is non-birefringent. As

15 such the presence of the heatspreader 18 no longer

16 interferes with polarisation selecting properties of the

17 birefringent filter 9 and so there are no additional

18 intracavity losses experienced on the output of the

19 VECSEL 1 as the laser is tuned (see Figure 6 below).

20

21 The lack of birefringence within the heatspreader 18 also

22 allows for an optimised anti-reflection coating to be

23 applied to the surface of the wedged face 20. It is

24 known to those skilled in the art that in order to

25 optimise an anti-reflection coating it is necessary that

26 the refractive index of the medium to which the coating

27 is to be applied is known to a high degree of accuracy.

28 Therefore, if the heatspreader 18 were to exhibit

29 birefringence (as is the case for Sapphire and Silicon

30 Carbide) two effective refractive indices would be

31 present. A direct result of this is that the effective

32 refractive index experienced by a propagating optical

33 field of a fixed polarisation would be critically

1   dependent on the orientation of the heatspreader 18

2   within the VECSEL 1, restricting alignment to a single

3   orientation only. Practically this would significantly

4   complicate the already difficult cavity alignment

5   process.

6

7   However, this is not the case with the single diamond

8   crystal heatspreader 18 thus permitting the incorporation

9   of the anti-reflection coating. The anti-reflection

10   coating acts to significantly reduces the power

11   modulation effects, caused by the presence of the

12   intracavity heatspreader 18, experienced when the 980 nm

13   VECSEL is wavelength tuned (see Figure 6 below).

14

15   Figure 4 provide some typical operational characteristics

16   of the described VECSEL 1 systems in the absence of the

17   birefringent filter 9 and the solid etalon 10. In

18   particular Figure 4 presents the 980 nm VESCEL output

19   power as a function of pump power, when the heatsink

20   temperature was maintained at 10°C. The pump power was

21   provided by a commercially available 200 μm fibre coupled

22   laser that generated a 25 W pump field at 808 nm. A 2%

23   output coupler 7 was employed so producing a maximum

24   output power of 1.75 W in a TEM_{00} mode with 6.2 W of pump

25   power.

26

27   On introducing the birefringent filter 9, the solid

28   etalon 10 and a 1% output coupler 7 to the cavity it is

29   possible to stabilise the output frequency of the device

30   to the side of a transmission peak of an external

31   reference cavity (not shown). The operational

32   characteristics of the 980nm VECSEL are shown in

33   Figure 5. The VECSEL 1 can be seen to operate at a

1 single   frequency   exhibiting   a   residual   frequency

2 fluctuation amounting to a linewidth of around 85 kHz

3 r.m.s.

4

5 By employing the first 6 and second piezoelectric

6 crystals 8 the curved cavity mirror 5 and the output

7 coupler 7, respectively, can be translated so as to allow

8 for the tuning of the output wavelength of the VECSEL 1.

9 A typical tuning curve for the 980nm VECSEL is presented

10 in Figure 6.   It should be noted that the modulation in

11 the output power can be seen to have been reduced to less

12 than 5%.

13

14 An   alternative   means   for   tuning   the   laser   cavity

15 comprises the introduction of a pair of Brewster plates

16 (not shown) into the laser cavity.   When the orientation

17 of the Brewster plates are rotated in conjunction with

18 the translational movement of the curved cavity 5 mirror

19 mounted   on   the   piezoelectric   crystal   6   the   output

20 wavelength of the laser can be scanned, as is known to

21 those skilled in the art.

22

23 As   will   be   apparent   to   those   skilled   in   the   art

24 alternative   semiconductor   wafer   structures   2   may   be

25 incorporated within the VECSEL 1 in order to provide

26 different operating wavelength ranges.   Furthermore, the

27 VECSEL outlined above has been described in relation to a

28 three   mirror   folded   cavity   chosen   for   ease   of

29 engineering.   However, it will again be readily apparent

30 to those skilled in the art that alternative cavity

31 arrangements may be employed without departing from the

32 scope of the invention.   For example the laser cavity may

16

1   be established between the Bragg reflector 4 and a curved

2   output coupler 7.

3

4   In alternative embodiments of the VECSEL the gain medium

5   14 can be back pumped by arranging the optical pump field

6   17 to be initially incident on the Bragg reflector region

7   4 of the semiconductor wafer structure 2, see Figure 7.

8

9   In particular Figure 7(a) presents a schematic

10 representation of an on axis back pumped VECSEL 22.   In

11 this embodiment the wafer structure 2 and the

12 heatspreader 18 are located within a mount 23 formed from

13 a high thermally conductive material e.g. copper. The

14 location of the heatspreader 18 and the wafer structure 2

15 may be achieved in a number of ways including simply

16 mechanically clamping the heatspreader 18 within the

17 mount 23 with a retaining flange 24, and/or bonding or

18 soldering the heatspreader 18 to the mount 23 and/or by

19 incorporating tapered edges on both the heatspreader 18

20 and the mount 23 so as to create a compression fit

21 between these components.   Suitable materials for

22 producing the retaining flange include copper, as per the

23 present embodiment, or Chemical Vapour Deposition (CVD)

24 diamond.

25

26 An aperture 25 is located within the retaining flange 24

27 so as to allow the pump field 17, provided by the optical

28 fibre 11, to be focused by a lens 26 so as to achieve the

29 required spot size within the gain medium 14. The design

30 of the GaAs substrate 13 and the Bragg reflector region 4

31 is such that they are substantially transparent to the

32 pump field 17. Propagation of the pump field 17 through

33 the GaAs substrate 13 can be enhanced by introducing an

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1 anti-reflection coating optimised for the wavelength of
2 the pump field 17.
3
4 In an alternative embodiment of the on axis back pumped
5 VECSEL (not shown) the lens 26 is removed and the optical
6 fibre is abutted directly against the wafer structure 2
7 via the aperture 25.
8
9 Figure 7(b) presents a schematic representation of an
10 alternative on axis back pumped VECSEL 27. In this
11 arrangement the GaAs substrate 13 has been removed from
12 the semiconductor wafer structure 2 so as to expose the
13 Bragg reflecting region 4. The removal of the GaAs
14 substrate 13 can be simply achieved mechanically or by
15 etching methods, techniques that are already known to
16 those skilled in the art.
17
18 Removal of the GaAs substrate 13 has several advantages.
19 In the first instance it reduces the wavelength
20 restrictions on the pump field 17 as it is now only
21 required to propagate through the Bragg reflecting region
22 4 before being absorbed within the gain medium 14.
23 Secondly, the removal of the GaAs substrate 13 also
24 allows for the incorporation of a second heatspreader 28
25 that is located in thermal contact with the Bragg
26 reflecting region 4, as shown schematically in Figure
27 7(b). This arrangement allows for additional improvement
28 of the operating characteristics of the VECSEL 27. As
29 the second heatspreader 28 is not an intra cavity element
30 the optical criteria placed on this component are
31 significantly reduced when compared with the intra cavity
32 heatspreader 18. Indeed this component can be made from
33 any material that is optically transparent to the pump

1   field and which exhibits good thermal conductivity

2   properties e.g. diamond, sapphire, Silicon Carbide, CVD

3   diamond and glass.

4

5   Figure 7(c) presents a schematic representation of a yet

6   alternative embodiment of the present invention, namely

7   an off-axis back pumped VECSEL 29. In this embodiment an

8   off axis pump field 17 is directed so as to back pump the

9   gain medium, in a similar manner to that described above,

10   through the employment of an off axis arrangement of the

11   optical fibre 11 and lens 26, as shown. An additional

12   intra cavity mirror 30, coated so as to efficiently

13   reflect the pump field 17, is then employed so as to

14   retro reflect any of the pump field 17 not absorbed on

15   the initial pass through the gain medium 14. With this

16   embodiment the efficiency of the absorption of the pump

17   field 17 within the gain medium 14 is increased so

18   improving the overall efficiency of the VECSEL 29.

19

20   It will be appreciated by those skilled in the art that

21   the advantages of the additional intra cavity mirror 30

22   can be harnessed within an on axis embodiment if this

23   mirror is suitably coated so as to reflect light at the

24   wavelength of both the pump field 17 and the VECSEL

25   operating wavelength. With this arrangement the intra

26   cavity mirror 30 thus functions to reflect any unabsorbed

27   pump field 17 back towards the gain medium 14 as

28   previously described, as well as acting as a normal

29   cavity mirror.

30

31   The above described VECSELs have all been described in

32   relation to optically pumped systems. However, it will

33   be appreciated by those skilled in the art that the

1   advantages of the heatspreader 18 can readily be

2   incorporated within an electrically pumped VECSEL systems

3   where the electrical contacts are arranged in such a

4   manner so as to allow the heatspreader 18 to be located

5   with gain medium 14.

6

7   The VECSELs described above all employ a non-birefringent

8   heatspreader that allows the full tuning potential of the

9   associated gain medium to be exploited. Single diamond

10   crystal is employed as the heatspreader since it provides

11   the required level of thermal conductivity so as to act

12   as an efficient heatspreader. The fact that the

13   heatspreader is non-birefringent means that there is no

14   detrimental interaction between the heatspreader and the

15   polarisation selecting properties of an intracavity

16   birefringent filter employed for coarse frequency

17   selection within the cavity. Furthermore, the fact that

18   heatspreader is non-birefringent allows the application

19   of an optimised anti-refection coating to a surface of

20   the heatspreader so as to significantly reduce the

21   modulation on the output power experienced by prior art

22   systems. This modulation of the output power can be

23   further reduced by arranging that the surface to which

24   the anti-reflection coating is applied is substantially

25   wedged.

26

27   The foregoing description of the invention has been

28   presented for purposes of illustration and description

29   and is not intended to be exhaustive or to limit the

30   invention to the precise form disclosed. The described

31   embodiments were chosen and described in order to best

32   explain the principles of the invention and its practical

33   application to thereby enable others skilled in the art

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20

1   to best utilise the invention in various embodiments and

2   with various modifications as are suited to the

3   particular use contemplated.   Therefore, further

4   modifications or improvements may be incorporated without

5   departing from the scope of the invention herein

6   intended.

7